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Flat roof design: the technical options

The term flat roof is commonly used in Codes and Standards to denote a roof which can be horizontal or which can have a fall of up to 8°, or even 10°, to provide drainage. At the upper end of this range the term low pitched is also used. However, whatever the actual definition and slope limitation, flat roofs are characterized by having a continuous waterproof layer. In some cases such roofs are used in situations where traditional pitched roof designs with a discontinuous waterproof layer could have been used. In other cases, especially on large buildings of irregular plan, they provide the only feasible solution. Experience suggests that high maintenance costs can occur with flat roofs. However, many of the problems that arise could have been avoided at the design and construction stages if designers and constructors had appreciated fully the limitations of the various design options, and had selected and applied correctly the one most suitable for their particular building taking into account the consequences and implications of failure and the costs of maintenance and replacement.

Roof requirements

Among the prime requirements for a roof is that, in conjunction with other relevant building elements, it should protect the occupants and if necessary the structure of the building it covers from the external environment. In practice, the roof designer usually has to provide a rainproof layer, means of excluding wind and snow, sufficient thermal insulation and a supporting structure. The structure must be able to resist wind and snow loads which can be more severe on flat than on pitched roofs. In the case of wind the uplift forces increase with decreasing roof pitch *(Digest 119)*. With snow the downward loading will tend to increase with decreasing pitch. The risk of high snow loading will also increase with higher thermal insulation. In addition the designer has to recognize the implication for his design arising from the activities of the occupants. Most activities generate moisture to some degree which increases the vapour pressure of the interior air over that surrounding the building. There can also be an air pressure excess at ceiling level due to stack effect and to wind movement around the building. Thus, unless prevented, there is a movement of the usually wetter interior air through the fabric of the building, including the roof, with the danger of condensation occurring on the colder parts of the construction. The roof designer has also to acknowledge the risk of failure of the waterproof layer itself or of leakage from some detail associated with it. Finally, the designer has to recognize not only that roofs have often to be completed in other than ideal weather conditions, so that the subsequent weathertightness performance may be affected, but also that poor workmanship can occur during construction which can result in the entry of water. Whether from condensation or leakage such wetting, especially if entrapped, can affect the properties of many materials involved in roof construction and indeed can result in actual deterioration, ie an irreversible change in properties. The implications of water ingress are, therefore, a major consideration in the design.

In meeting the requirements for a roof, the designer initially has a number of choices available to him. He can decide on a pitched roof with a discontinuous waterproof layer such as tiles, slates or profiled sheeting attached to a supporting structure or he can consider a horizontal or low-pitched roof with a continuous fully supported waterproof layer such as asphalt or multi or single-layer roofing membranes of bituminous felt, metal or plastics. If the decision is for a continuous, fully supported waterproof layer, then he has available to him a number of technical options for the design depending on the relative positions of the waterproof layer, the deck and the thermal insulation. This digest seeks to present in broad terms the advantages and disadvantages of the various arrangements for the three constituent parts.

The technical options

There are a number of possibilities for the arrangement of the three constituent parts of a roof with a fully supported continuous waterproof layer. However, there are only three arrangements for the relative positions of the deck, the insulation and the waterproof layer that are believed to be both practical and technically acceptable. These are known as the cold deck and the warm deck types of design, the latter having two variations usually referred to as sandwich and upside down (or inverted) construction. The choice of the arrangement for a particular building involves many considerations but it can be approached systematically through two options

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FIRST OPTION

Warm deck design

(Thermal insulation over deck)

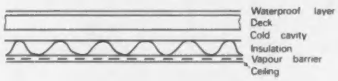
OR

Cold deck design

(Thermal insulation below deck)

Advantages
(a) Roof cavities not necessary unless required for services or provided with separate ceiling
(b) No ventilation required of any cavity (1)
(c) If fire barriers required (2) in any cavity then they can be readily accommodated without making special provisions for ventilation
(d) Continuous vapour barrier readily provided on flat decks to avoid condensation occurring in the insulation. On troughed decks more care is necessary to achieve a continuous vapour barrier.
(e) Structural deck protected from extremes of temperature
(1) In hazard conditions, ie swimming pools, any cavity can be pressurized with fresh ventilation air to prevent the ingress of wet air from the building interior which can degrade some materials.
(2) See BRE Digest 218

Disadvantages
(a) The waterproof layer and insulation has to be securely held to the deck against wind suction forces
(b) Replacement of waterproof layer may involve sacrificing insulation
(c) Insulation has to support maintenance traffic and equipment
(d) Failures in waterproof layer may be difficult to locate and repair.



Advantages
(a) Waterproof layer directly supported by deck
(b) Waterproof layer readily repaired
(c) Waterproof layer readily replaced without sacrificing insulation
(d) Non-rigid insulation can be laid in position (1)
(e) Water vapour leaks from occupied spaces can be ventilated from cavity.
(1) With high ventilation rates fibrous and loose fill insulation may need some securing.

Disadvantages
(a) Efficient ventilation of cavity to outside required (1)
(b) Ventilation of cavity difficult to achieve if solid strutting or fire barriers required (2)
(c) Air barrier/vapour check required at ceiling level and not readily installed without immediate or subsequent damage or puncturing
(d) Irregular roof shapes and abutting roofs difficult to ventilate (3)
(e) Care required to prevent ingress of snow and vermin through ventilation apertures.
(1) A clear aperture of 0.3% of plan area should be allowed. With this aperture area sufficient ventilation is normally provided by the pressure difference around buildings caused by wind. In hazard conditions, ie swimming pools, any cavity can be pressurized with fresh unheated air to prevent the build-up of wet air from the building interior which can degrade some materials.
(2) See BRE Digest 218
(3) Ventilation apertures required at least at each end of each cavity if necessary using through roof ventilators.

Proceed to Second Option

Proceed to Third Option

SECOND OPTION

Warm deck design - sandwich construction

(Thermal insulation between deck and waterproof layer)

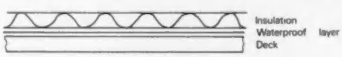
OR

Warm deck design - 'upside down' construction

(Thermal insulation over waterproof layer)

Advantages
(a) Waterproof layer readily accessible for inspection and repair
(b) Insulation can be secured by bonding or by mechanical fasteners. These latter do not penetrate waterproof layer.
(c) Structural deck protected from extremes of temperature

Disadvantages
(a) Continuous vapour barrier required on decks to avoid condensation in insulation (1)
(b) Water from leaks or rain falling during construction trapped in insulation
(c) Insulation has to support waterproof layer against maintenance traffic and equipment
(d) The large differential thermal movements between the waterproof layer and some plastic insulants has to be accommodated or a suitable thermally stable layer interposed (2)
(e) Because of the low thermal capacity of most insulants the temperature range of the waterproof layer in the service will be greater. Therefore faster ageing will occur at the higher temperatures and increased brittleness at lower.
(1) A continuous membrane is required. Joints should be bonded and flanking paths between the interior and the insulation avoided
(2) The daily thermal movement of polyurethane and isocyanurate based materials is less than that of polystyrene but can be greater than the seasonal moisture movement of fibre insulation board. However the risk to this latter material of any moisture ingress should be recognized.



Advantages
(a) Waterproof layer protected from sunlight from maintenance traffic and equipment and from extremes of temperature
(b) No separate vapour barrier required.

Disadvantages
(a) Waterproof layer not immediately accessible for inspection and repair
(b) Insulation has to be securely held against wind suction forces without puncturing the waterproof layer (1). When ballast is used the additional loading must be recognized in design and usually will result in higher costs
(c) Drainage can be more difficult and channels can become blocked
(d) Closed cell insulation required to maintain optimum thermal characteristics and to avoid frost attack
(e) Some loss of heat to rain water and to water from melting snow since this percolates under insulation and comes into contact with the warm waterproof layer; increased thickness of insulation therefore required.
(1) Usually the insulation can be secured by the weight of gravel or concrete slabs, which also help to protect it from mechanical damage and will improve sound insulation. However, the occurence of high wind suction forces and their effects should be considered.

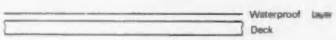
Proceed to Third Option

Roof slope

Having decided on the relative positions of the deck the insulation and the waterproof layer the designer now has to consider whether the roof should be horizontal or low pitched. The advantages and disadvantages of the alternatives provide a third option in the development of the outline design.

THIRD OPTION

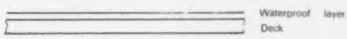
Low Pitched



Advantages
(a) Drainage positively controlled
(b) No retained water to feed small leaks(1)
(c) Scouring by rain provides cleaning action
(1) Slopes should be sufficient to accommodate irregularities in the surface due to movement of the constructional materials and to inaccuracies in the building process. Falls of 1.40 are recommended if acceptable to waterproof layer.

Disadvantages
(a) Can be difficult to accommodate on a large and irregular plan
(b) Gravel or other granules can be washed to gutter unless bonded
(c) Parapet may be required aesthetically, concealed gutters are prone to leak.

Horizontal



Advantages
(a) No need to construct to falls
(b) Gravel or other granules which may be used, eg for fire protection, is retained provided that the design and exposure are such that the risk of wind scour is obviated.

Disadvantages
(a) In practice water will be retained on uneven surface providing a continuous feed for leaks
(b) Dirt is not readily washed away

Proceed to outline design

Having reached this stage, the major technical decisions have been made and the designer can proceed to the detailed design and to the selection of materials for deck insulation and waterproof layer.

Costs

This digest is concerned primarily with the technical options available to the designer of horizontal and low-pitched roofs and not with the relative costs of the various solutions although these will often be very relevant not only in reaching the outline design stage but also in selecting from the wide variety of materials available. While some information is available or can be obtained readily on the initial costs of construction it should be emphasized that these data on their own provide only limited guidance to the designer as subsequent maintenance and replacement costs must also be recognized in assessing comparable solutions. At present little authoritative and sufficiently well-documented information is available on maintenance costs and on time to replacement, though BRE is trying to obtain such data. In the future, when this information becomes available, more precise guidance will be possible on the costs inherent in the alternative technical options.

Conclusions

When a designer needs to use a horizontal or low-pitched roof with a fully supported continuous waterproof layer on a building he has a number of choices available to him both in the type of design (warm or cold deck) and in the constructional arrangement he can use. Both design types have advantages and disadvantages; which should be employed in a particular situation will depend on a number of factors, such as whether or not cavity barriers for fire stopping have to be incorporated, whether in a cold deck design sufficient ventilation can be assured and whether in a warm deck the problems of insulation movement can be overcome. Above all, the degree of confidence in the design detail (eg parapets, upstands and edge trim) and in the quality of workmanship, particularly in avoiding leaks and in installing a continuous and effective vapour barrier, must be considered realistically. In assessing alternative designs both initial and maintenance costs and the life to replacement must be considered. Finally the need for regular inspections of roofs in service must be recognized. Only with a realistic and careful consideration of these factors will an effective design be evolved and the number and cost of problems associated at present with the use of horizontal and low-pitched roofs be reduced.

Further reading

BS CP 144 Roof coverings: Part 3:1970 Built-up bitumen felt
Part 4:1970 Mastic asphalt

BRE News, No 49; Autumn 1979; Survey of the falls of flat roofs

Cornish, JP and Hendry, IWL; Avoidance of condensation in roofs. BRE Current Paper CP1/75

Hide, WT; Inspection and maintenance of flat and low-pitched timber roofs, BRE Information Sheet IS 26/76

McIntyre, IS and Birch, DP; Considerations in the design of timber flat roofs. BRE Information Sheet IS 6/78

McIntyre, IS; Moisture in a timber-based flat roof of cold deck construction. BRE Information Paper IP 35/79

Other BRE Digests

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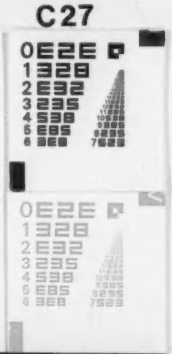
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